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A Methodology to Identify Low-carbon Passenger Transport Modes for Each Region in Asian Developing Countries

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***ABSTRACT*:** In Asian developing countries, rapid motorization in mega cities could increase the amount of CO_2 emissions from passenger transport. One of counter policies to CO_2 mitigation is to promote low-carbon transport modes in urban area. But CO_2 emissions per passenger-km from passenger transport depend on the number of passengers carried. It is also important to consider throughout lifetime CO_2 emissions generated from production of infrastructure and vehicles as well as from their operation.

This study proposes a method to identify low-carbon passenger transport modes for intra-urban travel by province-level region in Asian developing countries, using Life Cycle Assessment (LCA) approach. As intra-urban transport modes, the focus is on passenger car, Bus Rapid Transit (BRT), Light Rail Transit (LRT) and heavy rail. First, demand for use of each mode is estimated with the population density of the densely inhabited area of each province as transport density. Then, the number of operated vehicles to meet the demand is determined by transport density. Finally, Life Cycle CO_2 (LC-CO_2) emissions from infrastructure construction, vehicles manufacturing and operation are calculated by multiplying emission factors by the number of vehicles and their root length. The mode with the least LC-CO_2 is identified as a low-carbon transport mode for each province.

As case study areas, this study analyses provinces in Thailand by using Thesaban nakhons as a densely inhabited area. In addition, as future technological scenarios for Asia are considered with emission factors of Japan. The main results of this study are as follows. (1) In a scenario with emission factors of present Japan, BRT emits the least LC-CO_2 in provinces with highly-dense urban areas and in the remaining provinces and, the introduction of mass transit mode cannot reduce CO_2 emissions. (2) In a scenario with emission factors of future Japan, passenger car is selected as a mode that emits the lowest CO_2 in most provinces.

KEYWORDS: Low-carbon passenger transport system, life cycle assessment, Asian developing cities

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) proposes to halve emissions of green-house effect substances by 2050 to stabilize long-term climate conditions. As emission of carbon-dioxide (CO_2) in Asian developing countries will increase in coming years, we must offer measures to lower carbon emission in those countries.

Even in Asian countries, the ratio of CO_2 emissions originating from the transportation sector amounts to nearly twenty percent, and most emissions from passenger transportation come from passenger car use. Lowering carbon emissions in the passenger transportation sector is quite important. As developing countries have been motorizing with the development of their economies, a rapid increase of CO_2 emissions due to an increase of automobiles and heavy traffic congestion in urban areas is worrisome. Under the circumstances, constructing a low-carbon urban traffic system is needed for reducing emissions of CO_2 originating from passenger transport in Asian developing countries.

When designing a low-carbon transport system for urban areas of Asian developing countries, reducing the use of passenger automobiles by leading passengers to use mass-transit systems emitting less CO_2 is considered to be effective. However, public transport systems in Asian developing countries are not sufficient in volume of infrastructure or frequency of service. Furthermore, governments of those countries have been carrying out short-sighted stopgap measures by constructing many roads to cope with traffic congestion, which can promote automobile use in the long run. Thus, in constructing a low carbon passenger transport system for the medium and long range, introducing a transport system of trunk lines with low CO_2 emission vehicles can be considered a major pillar in designing a traffic system.

Furthermore, governments of those countries have been carrying out short-sighted stopgap-like measures by constructing many roads to cope with traffic congestion, which can, in turn, promote use of automobiles in the long span. Based on these factors, in constructing a low carbon passenger transport system in the medium and long range, introducing a transport system for trunk lines with low CO_2 emission vehicles can be considered a major pillar in designing a traffic system.

Although mass-transit is generally thought to emit less CO_2, introducing a mass-transit system does directly lead to lower carbon emissions. Efficiency of mass transit, in contrast to passenger cars, basically depends on ridership, and it only achieves lower emissions than passenger cars when the total CO_2 emissions are divided into sufficient man-kilometers. Accordingly, it will not be effective when the number of riders is less than a certain number.

Technical innovations will reduce CO_2 emissions in the transport sector, but the advances may lead to a decrease in the emission reduction achieved by introducing mass-transit. Railway systems, which emit far less than other transport modes, use electrical motors. As the energy effectiveness of the railway system is evaluated at nearly ninety percent, further improvement in reducing emissions may hardly be expected. On the other hand, the energy effectiveness of automobiles, which use fossil fuel for the engine, is estimated at around ten percent, allowing a strong possibility of reducing emissions from passenger cars by changing their power to electricity.

The authors presented a regional derivation of low-carbon transport in Japan using the life-cycle method in the previous study (Ito et al, 2010). According to the study, in 2050, there will be many regions in Japan where passenger cars are the least CO_2 emission transport mode because of improvements in the vehicle body and fuel efficiency, and reduction of transport density in mass-transit. This means that there will be some regions where introducing mass-transit will not reduce CO_2 emissions. Also, the study revealed that it will be necessary to build a new railway network totaling more than 100 kilometers in the Tokyo and Hanshin Districts, and tens of thousands of kilometers of railways around smaller cities, to reduce CO_2 emissions by strengthening the railway system. Figure 1 shows the result of selection of transport with the lowest CO_2 emission in Japan.

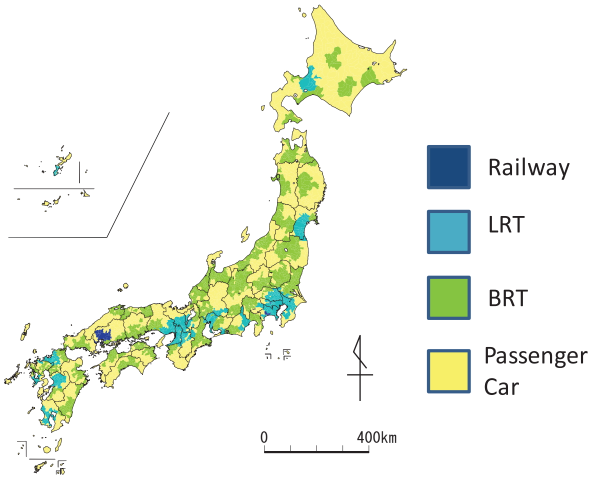

Figure 1 Passenger transport with the lowest CO_2 emission in Japan.

In Japan, as the population will remarkably decrease in the future, passengers using mass-transit are also expected to decrease, so the low-carbon effect of promoting mass-transit would be lessened accordingly. Contrary to Japan, mass-transit is considered to be an effective measure to reduce emission of CO_2 in Asian developing countries, as the population in those countries will increase steadily. In this study, we would like to present a regional derivation of low-carbon transport in Asian countries by applying a method we developed in Japan, to identify low-carbon passenger transport modes. In this study, we based our analysis on the assumption that innovation in transport technologies in major cities in these countries will be developed in the future to the same level as in Japan.

2. METHOD TO SELECT LOW-CARBON PASSENGER TRANSPORT

2.1 Transport subjects

In this study, Electric Overhead Railway, Light Rail Transit (LRT) and Bus Rapid Transit (BRT) were selected as the main subjects of the low-carbon transport system. The mass-transit emission of CO_2 by passenger cars was also compared. With regard to passenger cars, coexistence of gasoline-cars, hybrid-cars and electric-cars was assumed. The above-mentioned mass-transit systems have been planned or constructed by multiple cities in Asian developing countries as urban transit.

2.2 Estimate of emission of CO_2 by transit mode

As constructing a low-carbon transit system requires a long time and the transit system is expected to be used for a long period, the emission amount must be studied for a long span in evaluating the introduction of transit system. Especially, in the case of preparing new mass-transit, CO_2 will be emitted during construction of infrastructure and manufacturing of vehicles. To analyze the situation by adding these factors, we used Life Cycle Assessment (LCA) in the study. Specifically, we calculated a sum of CO_2 emission in each stage of constructing infrastructure, manufacturing vehicles and service of the transit system. We named the sum "System Life Cycle CO_2", and express it as <SyLC-CO_2>.

2.3 Method for calculating System Life Cycle CO_2

2.3.1 Emissions from constructing, maintaining and repairing roads

The emission was calculated by multiplying material input (Osada et al, 2006) in each stage by the basic unit of CO_2 emission and by total extension of the road.

2.3.2 Emission from manufacturing vehicles

Emissions originating from manufacturing vehicles were estimated by multiplying material input by the amount of energy consumed in assembling parts, and further by multiplying the result by the basic unit of CO_2 emission

(Architectural Institute of Japan, 1995). For railway vehicles, we used composition of stainless steel for electric trains and energy needed for manufacturing the vehicles (Ministry of the Environment, 2007). Emissions from manufacturing bus bodies were estimated by multiplying the estimate of CO_2 emission in manufacturing passenger cars by the proportion of weight of a bus body to that of a passenger car. The life of a railway vehicle was estimated to be 20 years, and that of a bus was estimated to be 15 years. Emissions at the time of scrapping vehicles were omitted. Only emissions at the time of manufacturing were included.

The number of buses required for operating the system, n, was calculated using the following formula:

$$n = \frac{N \times l}{V \times T} \times S \tag{1}$$

Each letter represents following:

N : number of buses operated daily,

l : total length of bus route to be operated,

V : scheduled speed,

T : hours per day to be operated,

S : number of cars per operation.

2.3.3 Emission of CO_2 originating from operation of the system

Emission of CO_2 originating from operation of the system was calculated by multiplying the amount of electricity and fuel consumed for basic unit-traveling-distance for each transport mode by the basic unit of emission of CO_2 for each transport mode (Ministry of the Environment, 2007). The amount of electricity and fuel consumed for unit-traveling-distance for each mass-transit mode was gained by interviewing staff of each transport organization (Osada et al, 2006). For basic-unit-emission of CO_2 by gasoline-engine passenger cars, the average value calculated by Matsuhashi and others in 1999 was used. For hybrid passenger cars, 10-15 mode fuel efficiency of the types concerned was converted to real efficiency using the prediction formula (Kudo et al, 2007). With regard to electric cars, as we cannot obtain a real value of fuel efficiency, the publicized amount, dividing the traveling distance for one charge of electricity into electricity consumed while traveling, was multiplied by the basic unit emission of CO_2 per amount electricity consumed(Architectural Institute of Japan, 1995).

In order to estimate the emission amount per man-kilometer, the number of passengers who will use the transport must be specified. In this study, we expressed it as density of transport. In the previous study (Ito et al, 2010), emission in Japan was estimated as the relation of SyLC-CO_2 per man-kilometers of traveling passengers on each transport mode with the density of transport. Figure 2 illustrates the relation of density of transport with SyLC-CO_2 in 2000 and 2050. Mass-transit decreases SyLC-CO_2 per man-kilometer of transport, because the emission of CO_2 allocated to man-kilometers decreases according to the increase of the transit density. As the emission of CO_2 by BRT per basic unit length of road extension lessens with progress of construction of infrastructure, BRT will be the least SyLC-CO_2 among the mass-transit modes when the transit density is low. SyLC-CO_2 of BRT's meets that of LRT's at the transit density of 6,000 (man/day). If the density surpasses 6,000, LRT, emitting less CO_2 while traveling, emits the least SyLC-CO_2.

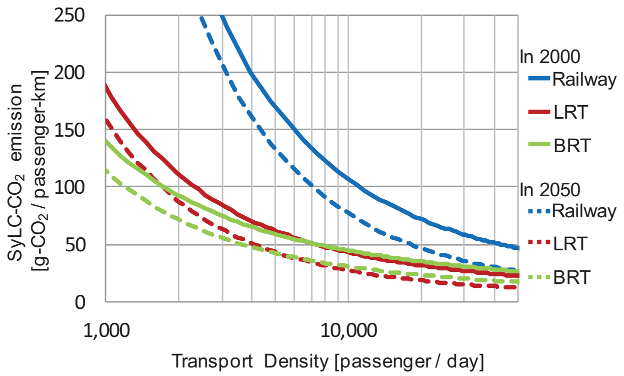

Figure 2 Transport Density and SyLC-CO_2 of Each Transit Mode

2.4 Estimate of transit density in considering local characteristics

As population density is considered to represent a local characteristic, we assumed that population density would decide transport density of mass-transit. In analyzing transport systems in main parts of traffic, Go and others analyzed relations of the real transit density and scheduled speed of subway, trams, Automated Guideway Transit, AGM and monorail with local characteristics. As a result, transit density had a rather positive correlation with population density in the densely inhabited district, DID, of the central city in the local traffic area. Figure 3 illustrates the formula of relation between transit density and population density in DID for railway, LRT and BRT.

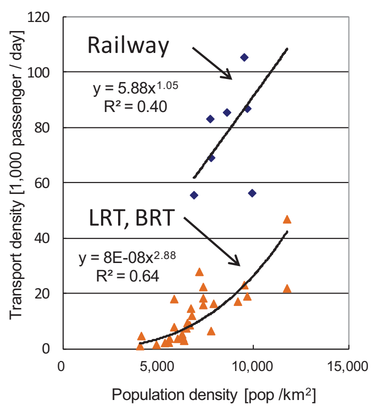

Figure 3 Population density and transport density

In this study, we would like to identify the least SyLC-CO_2 transit system by region in Asian developing countries by using these formulas.

3. APPLICATION TO AN ASIAN DEVELOPING COUNTRY

In this study, we would like to identify low-carbon passenger transport in Thailand.

3.1 Present situation of passenger transport in cities in Thailand

In Asian developing countries, motorcycles or scooters have been widely used and individual transit called para-transit has been developed. For example, in Bangkok, the capital of Thailand, the number of holding motorcycles and passenger cars has been rapidly increased according to growth of economy. The number of passenger cars privately owned, 220,000 in 1980, increased by seven times to 1.54 million in 2000. Further, traveling distance by passenger cars has been doubled, and as the result the city becomes highly depending on passenger cars. However, since construction of infrastructures as highways has been delayed, the city grows to a world-famous traffic-congestion city.

Traffic modes for citizens in Bangkok are mainly divided into three sectors: passenger cars, motorcycles and buses. Buses have many routes to cover the whole city, but they have the weakness of being directly affected by traffic congestion. Railway systems have been constructed since around 2000: Sky Train was opened in 1999, Subways in 2004 and Airport-Link Line was opened in 2010.These railway lines are very convenient, because they are not affected by traffic congestion on streets, and each line is interconnected at several stations. However, as the total length of operation is quite short, 73.3 kilometers at the end of 2010, the number of

Table 1 Population, area and population density of the top 15 areas in *Thesaban nakhon*

Thesaban nakhon	Province	Population [pop]	Area [km^2]	Density [pop/km^2]
Bangkok	Bangkok	5,701,394	1,568	3634
Nonthaburi	Nonthaburi	261,474	38.9	6722
Pakkret	Nonthaburi	178,907	36.0	4964
Hat Yai	Song Khla	158,122	21.0	7530
Nakhon Ratchasima	Nakhon Ratchasima	141,714	37.5	3779
Chaing Mai	Chaing Mai	141,361	40.2	3515
Udon Thani	Udon Thani	137,948	47.7	2892
Surat Thani	Surat Thani	125,730	69.0	1823
Khon Kaen	Khon Kaen	113,754	46.0	2473
Nakhon Si Thammarat	Nakhon Si Thammarat	108,907	22.6	4827
Pattaya	Chonburi	107,944	20.8	5190
Nakhon Sawan	Nakhon Sawan	89,682	27.9	3218
Ubon Ratchathani	Ubon Ratchathani	83,173	29.0	2864
Nakhon Pathom	Nakhon Pathom	81,204	19.9	4091
Rangsit	Pathum Thani	77,969	20.8	3749

passengers is not great. If the number of passengers is increased by construction of line extensions as planned, traffic congestion will be relieved.

3.2 Data of cities in Thailand

For analysis, data relating to population density of major cities in Thailand are shown hereunder.

A “thesaban” is a regional unit defining an area of a city. Among thesabans, a city district having a population density higher than a certain figure is called a “thesaban nakhon”. Although the specific definition of the thesaban nakhon has been repeatedly renewed, the basic definition is an area of the city having a population of more than 50,000 and population density of more than 3,000/km2. Table 1 shows a list of population, area and population density of the top 15 areas, adding Bangkok and Pattaya, which have similar size of city districts to thesaban nakhon. The city district of Bangkok, the capital city of Thailand, has a much wider area than other cities; however, the population density is not regarded as exceptionally high.

Thus, the thesaban nakhon is considered to be equivalent to a DID in Japan. In view of this, we tried to use the population density of thesaban nakhon to identify the least CO_2 emission transport in Thailand by applying the method developed to select the mass-transit using the index of population density in DID in Japan. In the analysis for Japan, neighboring towns are collected to form a unit of a traffic zone to select transport modes in consideration of the number of commuters and students, distance or range. However in this study, due to lack of data, we analyzed the case of Changwat, which is similar to a Japanese prefecture in size and in functions.

4. RESULTS OF ESTIMATE OF THE LEAST CO_2 EMITTING TRANSPORT

Figure 4 shows the result of the estimate of the least SyLC-CO_2 transport in Thailand in 2000. According to the study, the least SyLC-CO_2 transport in Thailand is estimated to be passenger cars in many regions. One of the reasons is rapid urban sprawl due to which transport density for mass-transit has not been increased.

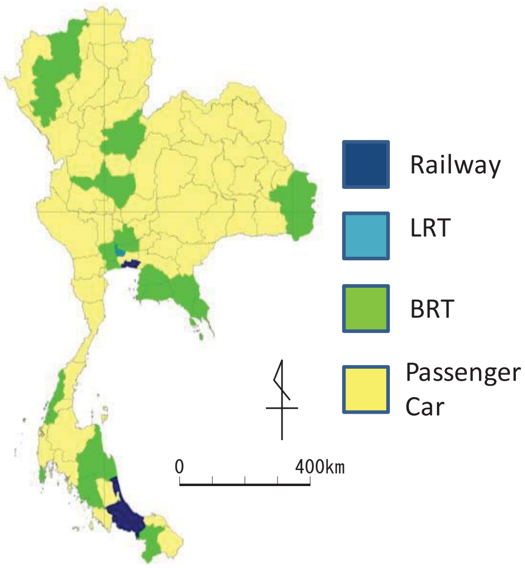

Figure 4 Passenger transport with the lowest CO_2 emission in Thailand

Table 2 shows the results of the least SyLC-CO_2 for the thesaban nakhon regions in 2000 and 2050. In Bangkok, the capital city, BRT is identified as the least SyLC-CO_2 transport because of the comparatively low population density, despite the large population. The regions where railways like LRT become effective to reduce CO_2 emission number only four (4) out of 29. In 16 regions, BRT is selected as the least SyLC-CO_2 transit.

In 2050, in almost all regions, the least SyLC-CO_2 transport will be altered to passenger cars from BRT. This results from the assumption that technological innovation of automobiles will be advanced in the period. As a result, regions where mass-transit such as BRT, LRT and railways are the least SyLC-CO_2 will be reduced to nine.

Table 2 The number of thesaban nakhon regions arranged by the least SyLC-CO_2 passenger transport

The least SyLC-CO_2 passenger transport	In 2000	In 2050
Passenger Car	9	20
BRT	16	4
LRT	1	2
Railway	3	3

5. CONCLUSION

In this study, we identified the main transport for Changwat, Thailand to have the capability of realizing a low-carbon transport system. As the result, the following are suggested:

(1) In Thailand, as the population has been concentrated in Bangkok, BRT is identified in Bangkok, while in many other regions, it has been shown that the introduction of mass-transit will not lead to reduced CO_2 emission.

(2) When technological innovation advances as fast as in Japan, it is shown that in the regions where BRT now emits the least CO_2, passenger cars will be the least, in place of BRT.

In this study, a trend experienced in Japan was reflected strongly, because we employed a model based on population density of DID in Japan to express the relations between transit density and local characteristics. For further study, we must analyze more data in a wider range of cities in developing countries. At the same time, we must analyze the transit volume by reflecting the structure of cities. With regard to progress of technical innovation, although we used the ratio of improvement in Japan in this study, we consider that we must determine the ratio of improvement of technical innovation by considering the difference of composition of vehicles in the cities in Asian developing countries.

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